



Chemistry

Higher level

Paper 3

Friday 13 May 2016 (morning)

Candidate session number

1 hour 15 minutes

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Instructions to candidates

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Section A: answer all questions.
- Section B: answer all of the questions from one of the options.
- Write your answers in the boxes provided.
- A calculator is required for this paper.
- A clean copy of the **chemistry data booklet** is required for this paper.
- The maximum mark for this examination paper is **[45 marks]**.

Option	Questions
Option A — Materials	3 – 8
Option B — Biochemistry	9 – 14
Option C — Energy	15 – 21
Option D — Medicinal chemistry	22 – 26



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Answers written on this page
will not be marked.

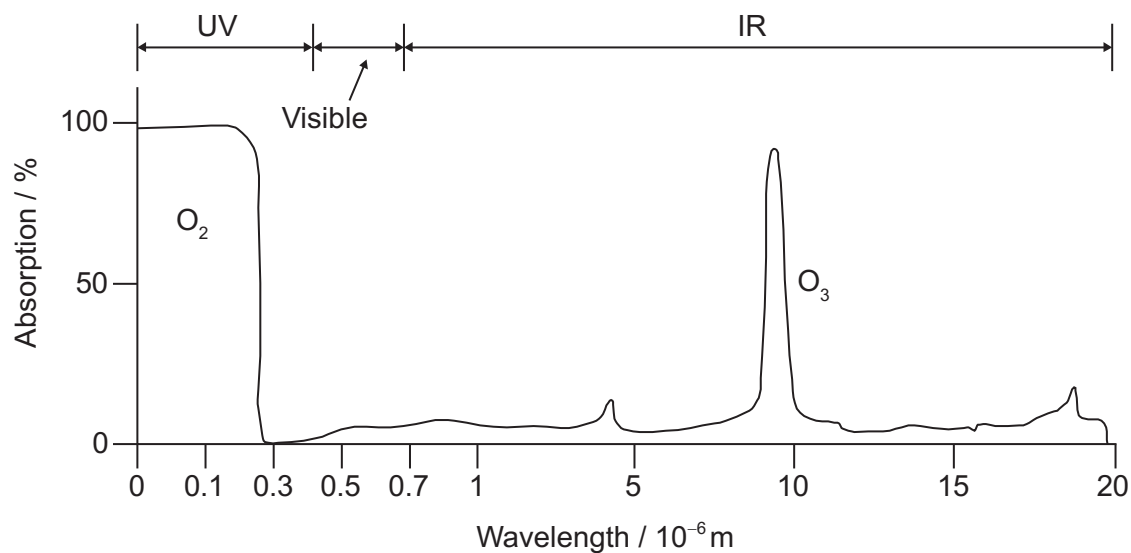


Section A

Answer **all** questions.

1. The absorption of infrared (IR) radiation by molecules in the atmosphere affects global temperatures.

Graph of IR absorbances for oxygen and ozone molecules



[Source: adapted from 2007 Thomson Higher Education, www.acs.org]

- (a) Using the graph, state, giving your reasons, whether or not oxygen and ozone are greenhouse gases.

[2]

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(This question continues on the following page)



40EP03

Turn over

(Question 1 continued)

- (b) The following data has been compiled for a range of molecules that may be found in the atmosphere.

Molecule	Integrated IR intensity* / km mol ⁻¹	Molecular dipole moment / Debyes	GWP** over 100 years
CO ₂	25.7	0	1
CCl ₄	443.7	0	1 400
CCl ₃ F	705.2	0.45	4 750
CCl ₂ F ₂	970.1	0.51	10 900
CClF ₃	1199	0.50	14 400
CF ₄			

[Sources: “Identifying the Molecular Origin of Global Warming”, Partha P Bera, Joseph S Francisco and Timothy J Lee. Published in J. Phys. Chem. A, Vol. 113, No. 45, 2009 and accessed from www.r744.com]

*Integrated IR intensity is a measure of the extent to which the molecule absorbs infrared radiation passing through the atmosphere.

**GWP: The global warming potential (GWP) is a relative measure of the total contribution of the compound to global warming over the specified time period. It is compared to the same mass of CO₂, which has a GWP of 1.

- (i) Use the integrated IR intensity data in the table to estimate the value for CF₄. [1]

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- (ii) Explain the increase in molecular dipole moment as one chlorine atom in CCl₄ is replaced with fluorine to produce CCl₃F. [2]

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(This question continues on the following page)



(Question 1 continued)

- (iii) Outline the relationship between GWP over 100 years and integrated IR intensity for CCl_4 , CCl_3F , CCl_2F_2 and CClF_3 .

[1]

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- (iv) Examine whether there is a general relationship between integrated IR intensity and molecular dipole moment.

[1]

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- (v) CCl_2F_2 and CClF_3 were developed for use as refrigerants but are now being replaced by other chemicals. Comment on their use with reference to values in the table and other environmental concerns.

[2]

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2. A student wished to determine the concentration of a solution of sodium hydroxide by titrating it against a $0.100 \text{ mol dm}^{-3}$ aqueous solution of hydrochloric acid.

4.00 g of sodium hydroxide pellets were used to make 1.00 dm^3 aqueous solution.

20.0 cm^3 samples of the sodium hydroxide solution were titrated using bromothymol blue as the indicator.

- (a) Outline, giving your reasons, how you would carefully prepare the 1.00 dm^3 aqueous solution from the 4.00 g sodium hydroxide pellets.

[2]

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- (b) (i) State the colour change of the indicator that the student would see during his titration using section 22 of the data booklet.

[1]

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- (ii) The student added the acid too quickly. Outline, giving your reason, how this could have affected the calculated concentration.

[2]

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(This question continues on the following page)



(Question 2 continued)

- (c) Suggest why, despite preparing the solution and performing the titrations very carefully, widely different results were obtained.

[1]

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Turn over

Section B

Answer **all** of the questions from **one** of the options.

Option A — Materials

3. Iron may be extracted from an ore containing Fe_2O_3 in a blast furnace by reaction with coke, limestone and air. Aluminium is obtained by electrolysis of an ore containing Al_2O_3 .

- (a) State the overall redox equation when carbon monoxide reduces Fe_2O_3 to Fe. [1]

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- (b) Predict the magnetic properties of Fe_2O_3 and Al_2O_3 in terms of the electron structure of the metal ion, giving your reasons. [2]

Fe_2O_3 :

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Al_2O_3 :

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(Option A continues on the following page)



(Option A, question 3 continued)

- (c) Molten alumina, $\text{Al}_2\text{O}_3(\text{l})$, was electrolysed by passing $2.00 \times 10^6 \text{ C}$ through the cell.
Calculate the mass of aluminium produced, using sections 2 and 6 of the data booklet. [2]

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- (d) (i) Outline the cause of electrical resistance in metallic conductors. [1]

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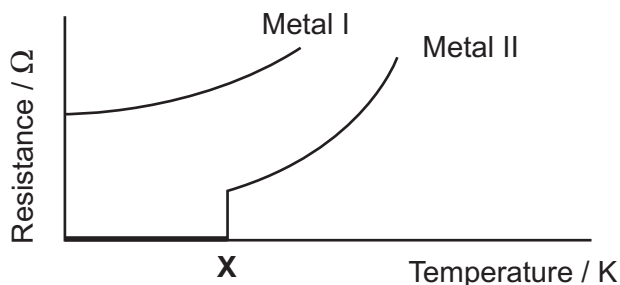
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(Option A continues on the following page)



(Option A, question 3 continued)

- (ii) The resistance of two metals was measured as a function of temperature. The following graph was obtained.



Explain the behaviour of metal II below temperature X in terms of the Bardeen–Cooper–Schrieffer (BCS) theory.

[3]

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- (e) (i) Polonium metal has a simple cubic structure. Construct a unit cell diagram and state the coordination number of each atom.

[2]

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(Option A continues on the following page)



(Option A, question 3 continued)

- (ii) X-ray diffraction was carried out on polonium using radiation with a wavelength of 8.80×10^{-11} m. The first order maximum in the diffraction pattern was observed at an angle of 13.0° . Determine the distance, in m, between layers of polonium atoms using section 1 of the data booklet. [1]

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4. Nanocatalysts have large surface areas per unit mass.

- (a) Identify **one** concern of using nanoscale catalysts. [1]

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- (b) Explain how zeolites act as selective catalysts. [2]

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(Option A continues on the following page)



(Option A, question 4 continued)

- (c) Carbon nanotubes, which can be produced by the HIPCO process, show great potential as nanocatalysts. Identify the catalyst and conditions used in the HIPCO process.

[2]

Catalyst:

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Conditions:

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5. Describe how the structures of ceramics differ from those of metals.

[2]

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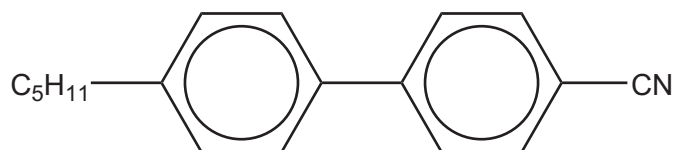
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(Option A continues on the following page)



(Option A continued)

6. Biphenyl nitriles, such as the molecule shown below, were the first thermotropic liquid crystal molecules to be synthesized.



- (a) Explain why the nitrile group enables these molecules to be used in liquid-crystal displays (LCDs).

[2]

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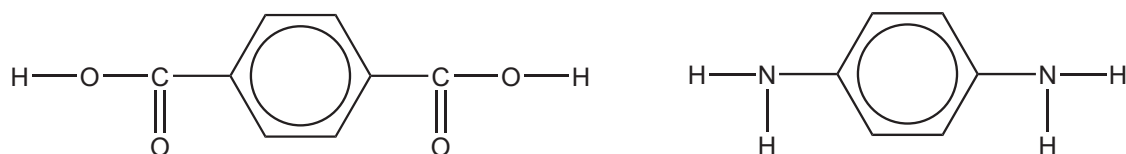
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- (b) (i) The monomers from which Kevlar® is produced are given below.



Deduce the formula of the repeating unit of Kevlar®.

[1]

(Option A continues on the following page)



(Option A, question 6 continued)

- (ii) State the structural feature of Kevlar[®] that is primarily responsible for its strength. [1]

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7. Chloroethene undergoes polymerization with a free-radical initiator to produce the atactic form of polychlorethene (PVC).

- (a) Explain, in molecular terms, why PVC becomes more flexible and softer when a plasticizer is added. [2]

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- (b) Suggest an environmental issue associated with the use of PVC. [1]

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(Option A continues on the following page)



(Option A continued)

8. Metal ions may cause unwanted environmental effects.

- (a) The presence of iron(III) ions can catalyse the formation of hydroxyl radicals from O_2^- and H_2O_2 in the Haber–Weiss reaction. State the equations for this process.

[2]

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- (b) Zinc ions, toxic to aquatic life, may be removed by adding a solution containing hydroxide ions. Determine the concentration of zinc ions in a saturated solution of zinc hydroxide at 298 K using information from section 32 of the data booklet.

[2]

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End of Option A

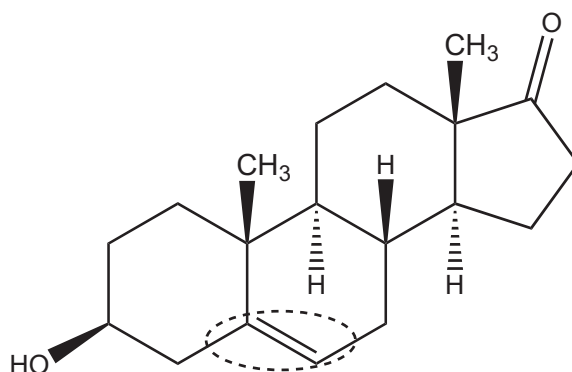


Option B — Biochemistry

9. Dehydroepiandrosterone (DHEA) is a substance banned under the World Anti-Doping Code.

- (a) (i) State the name of the functional group circled in the DHEA molecule shown below.

[1]



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- (ii) Identify the characteristic of this structure that classifies it as a steroid.

[1]

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- (b) The production of banned steroids has ethical implications. Suggest a reason why steroid research might be supported.

[1]

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(Option B continues on the following page)



(Option B continued)

10. Amino acids, shown in section 33 of the data booklet, can be combined to form polypeptides and proteins.

- (a) Deduce the structures of the most abundant form of glycine in three buffer solutions at pH 1.0, 6.0 and 11.0. Glycine $pK_{a1} = 2.4$; $pK_{a2} = 9.8$.

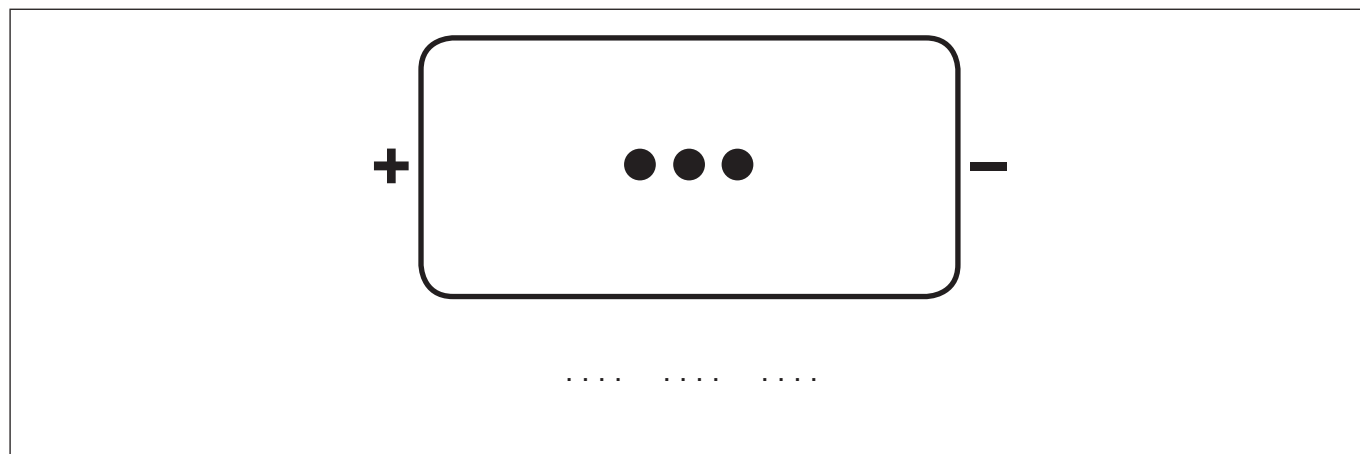
[3]

pH 1.0	pH 6.0	pH 11.0

- (b) A tripeptide, **X**, containing leucine (Leu), lysine (Lys) and glutamic acid (Glu) is hydrolysed and separated by gel electrophoresis in a buffer solution with a pH of 6.0.

- (i) Predict the result of the electrophoresis by labeling the three spots below with the names of the amino acids.

[2]



- (ii) Deduce the number of tripeptides that could be formed by using the three amino acids of tripeptide **X**.

[1]

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(Option B continues on the following page)



(Option B, question 10 continued)

- (c) (i) Serine is a chiral amino acid. Draw both enantiomers of serine. [1]

- (ii) State the enantiomeric form of serine found in proteins. [1]

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11. Glucose, $C_6H_{12}O_6$, is a monosaccharide that our body can use as a source of energy.

- (a) Deduce the equation for the cellular respiration of glucose. [1]

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- (b) Calculate the energy, in kJ, produced from 15.0 g of glucose if its enthalpy of combustion is $-2803 \text{ kJ mol}^{-1}$. [2]

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(Option B continues on the following page)



(Option B, question 11 continued)

- (c) Glucose is the basic building block of starch which can be used to make bioplastics. Outline **two** advantages and **two** disadvantages of biodegradable plastics. [4]

Two advantages:

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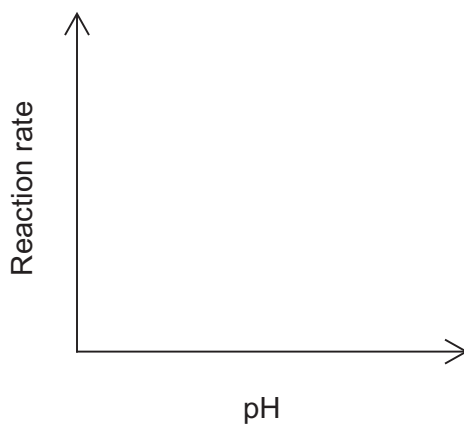
Two disadvantages:

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- (d) Bioplastics are broken down by enzyme catalysed reactions. Sketch a graph illustrating how the rate of this reaction varies with pH. [1]



(Option B continues on the following page)

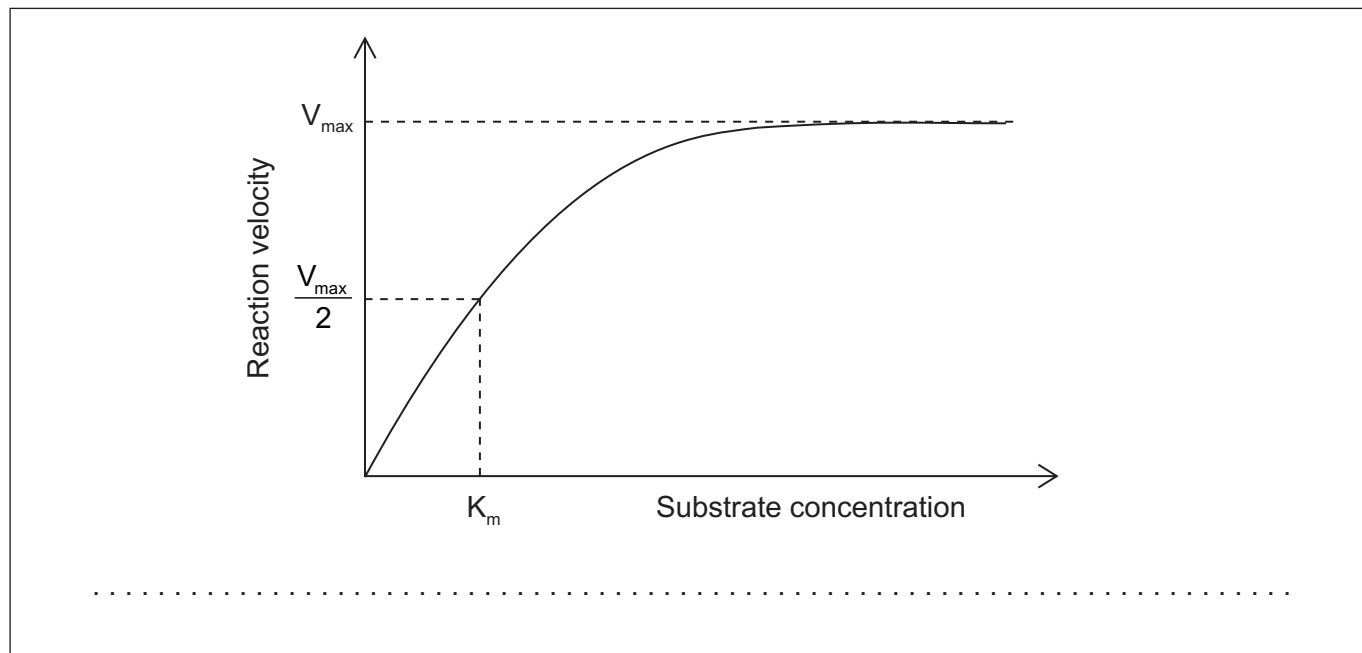


(Option B continued)

12. Enzymes play an important role in the functioning of our bodies.

- (a) The graph below shows a Michaelis–Menten plot for an enzyme. Sketch and label two curves on the graph below to show the effect of adding a competitive and non-competitive inhibitor.

[2]



- (b) Enzyme solutions are prepared in buffers. Determine the pH of a buffer solution containing $2.60 \times 10^{-3} \text{ mol dm}^{-3}$ ethanoic acid and $3.70 \times 10^{-3} \text{ mol dm}^{-3}$ sodium ethanoate. Refer to sections 1 and 21 of the data booklet.

[2]

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(Option B continues on the following page)



(Option B continued)

13. Spinach is an excellent source of vitamins A and C.

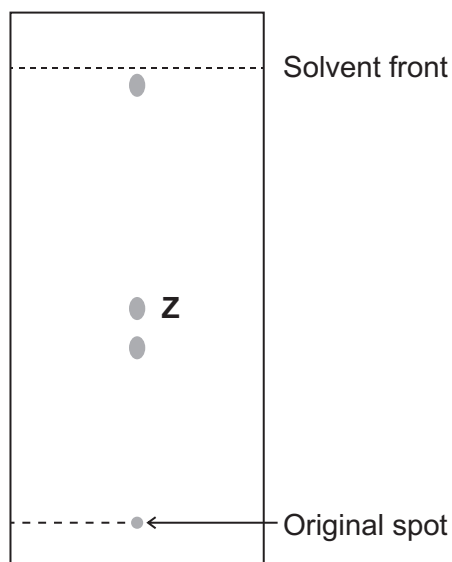
- (a) Identify one structural characteristic in vitamins A and D which makes them more similar to each other than they are to vitamin C using section 35 of the data booklet. [1]

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- (b) The pigments from spinach were separated using chromatography. Identify **Z** by calculating its R_f value and using the data table. [1]



Pigment	R_f value
Xanthophyll	0.35
Chlorophyll a	0.60
Chlorophyll b	0.50
Carotene	0.95

R_f :

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Z:

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(Option B continues on the following page)



(Option B continued)

14. Hemoglobin contains a heme group with an iron(II) ion.

- (a) Outline how the oxygen saturation of hemoglobin is affected by changes in the blood plasma.

[3]

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- (b) Explain why foetal hemoglobin has a greater affinity for oxygen.

[2]

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End of Option B



Option C — Energy

15. Hexane, C_6H_{14} , is not a suitable fuel for internal combustion engines as it has a tendency to auto-ignite, a cause of “knocking”.

- (a) (i) Hexane can be converted to different organic products in a reforming process. Identify **one** of these products.

[1]

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- (ii) Suggest why the product in (a)(i) has a lesser tendency to auto-ignite than hexane.

[1]

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- (b) (i) Octane, C_8H_{18} , can undergo complete combustion under suitable conditions. Calculate the specific energy of octane, in kJ g^{-1} , using sections 1, 6 and 13 of the data booklet.

[1]

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(Option C continues on the following page)



(Option C, question 15 continued)

- (ii) The specific energy of ethanol is 29.7 kJ g^{-1} . Evaluate the addition of ethanol to octane (or its isomers) for use as a fuel in motor vehicles, giving **one** advantage and **one** disadvantage. [2]

Advantage:

.....

Disadvantage:

.....

- (c) Coal can be heated with steam to produce synthetic natural gas. Formulate an equation to show the formation of methane, $\text{CH}_4(\text{g})$, from coal, $\text{C}(\text{s})$, and steam, $\text{H}_2\text{O}(\text{g})$. [1]

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16. Vegetable oils and diesel fuel have similar energy content but vegetable oils are not usually used as fuels in internal combustion engines.

- (a) Transesterification reactions allow waste cooking oils to be converted to biofuels. Identify a reagent and catalyst required for this conversion. [2]

Reagent:

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Catalyst:

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(Option C continues on the following page)



(Option C, question 16 continued)

- (b) Scientists around the world conduct research into alternatives to fossil fuels. Suggest why collaboration is important.

[1]

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17. Fusion and fission reactions are important nuclear reactions.

- (a) Curium, ^{240}Cm , was synthesized by bombarding thorium nuclei, ^{232}Th , with carbon-12 nuclei. State a balanced equation for this reaction.

[1]

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- (b) Uranium-235 has a half-life of 7.038×10^8 years.

- (i) Calculate the radioactive decay constant, λ , for ^{235}U using section 1 of the data booklet.

[1]

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- (ii) Determine the time required for the mass of ^{235}U in a sample originally containing 1.000 g of ^{235}U to decrease to 0.125 g.

[1]

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(Option C continues on the following page)



40EP25

Turn over

(Option C, question 17 continued)

- (iii) Explain why the radiation released from nuclear fuel and nuclear waste is dangerous to living organisms.

[2]

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- (c) (i) Calculate the mass defect, in kg, for the formation of helium-4 using sections 2 and 4 of the data booklet.

[2]

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- (ii) Determine the binding energy per nucleon of a helium-4 nucleus, in kJ nucleon^{-1} , using your answer to (c)(i) and section 2 of the data booklet.
(If you have no answer to (c)(i), use $5.00 \times 10^{-29} \text{ kg}$, although this is not the correct answer.)

[1]

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(Option C continues on the following page)



(Option C continued)

- 18.** Atmospheric carbon dioxide and aqueous carbon dioxide in the oceans form a heterogeneous equilibrium.

Explain the effect of increasing concentrations of atmospheric carbon dioxide on the pH of the oceans, including an equation in your answer.

[3]

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- 19.** Carbon dioxide, CO_2 , is a greenhouse gas. Outline, in molecular terms, how carbon dioxide molecules absorb infrared radiation.

[2]

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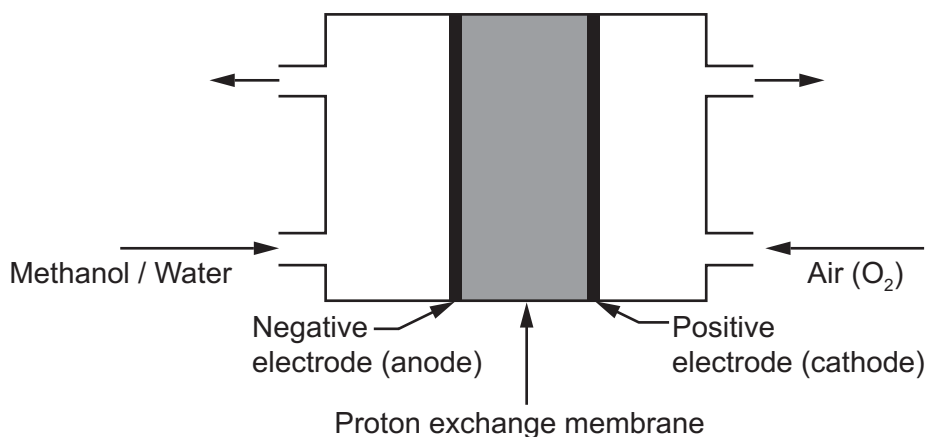
(Option C continues on the following page)



(Option C continued)

20. Fuel cells and rechargeable batteries are useful sources of energy.

- (a) One type of fuel cell contains a proton exchange membrane between electrodes and uses aqueous methanol as the fuel.



State half-equations for the reactions which occur at the negative and positive electrodes.

[2]

Negative electrode (anode):

.....

Positive electrode (cathode):

.....

- (b) Suggest **one** advantage and **one** disadvantage of a fuel cell over a lead–acid battery as an energy source in a motor vehicle.

[2]

Advantage:

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Disadvantage:

.....

(Option C continues on the following page)



(Option C continued)

21. Traditional photovoltaic cells are made from n-type and p-type semiconductors.

- (a) State how n-type and p-type doping of silicon is achieved and the nature of electric charge carriers in each case.

[2]

n-type:

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p-type:

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- (b) In dye-sensitized solar cells (DSSCs), nanoparticles coated with a black dye are trapped between electrodes in a liquid electrolyte. Explain the high efficiency of the DSSC structure.

[2]

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End of Option C



Option D — Medicinal chemistry

- 22.** Penicillin was one of the first antibiotics to be isolated and identified for its ability to treat bacterial infections.

(a) Explain the importance of the beta-lactam ring in the antibiotic activity of penicillin. [3]

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(b) Identify **two** dangers of the overuse of antibiotics. [1]

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- 23.** Opiates have been used for thousands of years to alleviate pain. The structures of opiates are found in section 37 of the data booklet.

(a) Diamorphine (heroin) can be synthesized from morphine. Identify the reagent necessary for this reaction and the by-product of this reaction. [2]

Reagent	By-product
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(Option D continues on the following page)



(Option D, question 23 continued)

- (b) Discuss how the differences in structure between morphine and diamorphine affect their absorption in the body.

[3]

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(Option D continues on the following page)



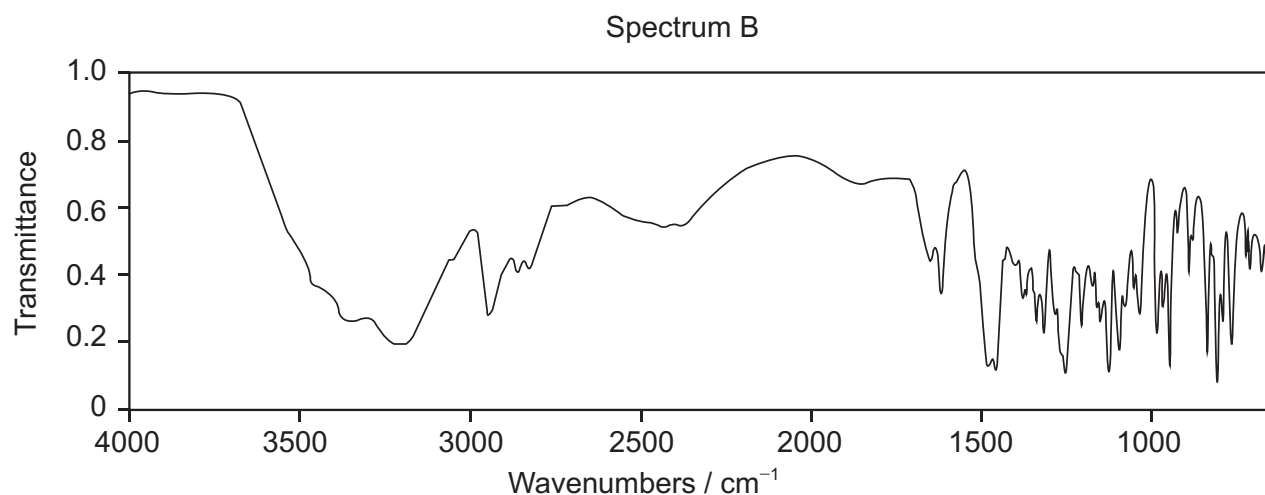
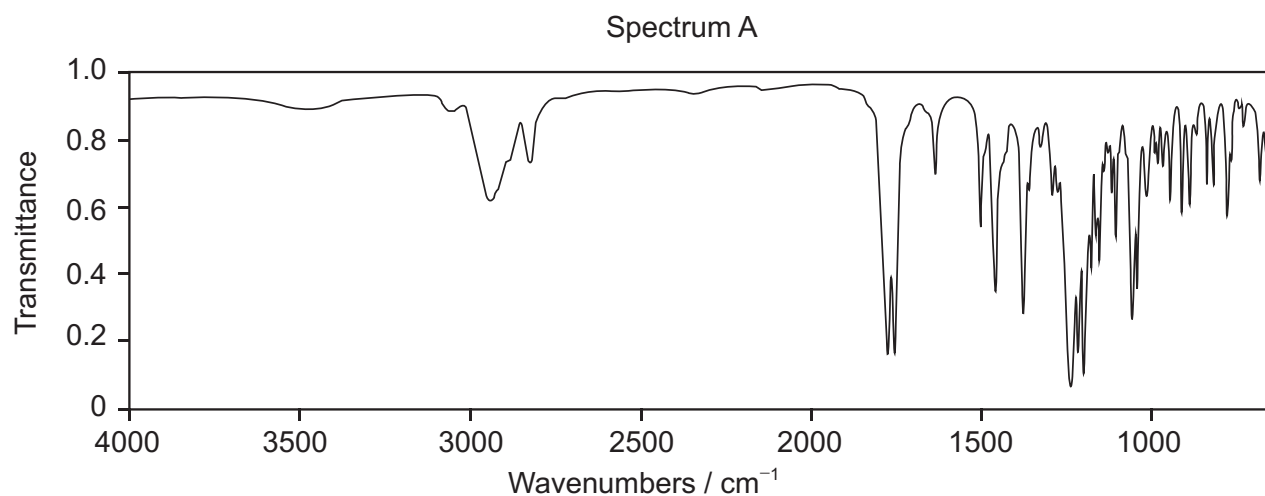
40EP31

Turn over

(Option D, question 23 continued)

- (c) Using sections 26 and 37 of the data booklet, deduce, giving **two** reasons, which spectrum is that of morphine and which is diamorphine.

[2]



[Source: <http://webbook.nist.gov>]

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(Option D continues on the following page)



40EP32

(Option D continued)

24. Magnesium hydroxide is the active ingredient in a common antacid.

- (a) Formulate the equation for the neutralization of stomach acid with magnesium hydroxide.

[1]

<p>.....</p> <p>.....</p>

- (b) Compare and contrast the use of omeprazole (Prilosec) and magnesium hydroxide.

[3]

<p>.....</p> <p>.....</p> <p>.....</p> <p>.....</p> <p>.....</p> <p>.....</p> <p>.....</p>
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25. Radioactive isotopes are used in a variety of medical procedures including medical imaging and radiotherapy.

- (a) Identify examples of **two** types of medical radioactive waste and how **each** must be treated for proper disposal.

[2]

Example	Treatment
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.....

(Option D continues on the following page)



40EP33

Turn over

(Option D, question 25 continued)

- (b) Lead-212 is a radioisotope that is used in the treatment of cancer. It is produced from another radioisotope by alpha decay. Formulate the equation for its production. [2]

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- (c) Identify **one** advantage of using Targeted Alpha Therapy (TAT) and **one** form of cancer commonly treated by this method. [2]

Advantage:

.....

Cancer treatment:

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- (d) Technetium-99m, used for radioimaging scans, has a half-life of 6.01 hours. Calculate the mass of a 5.80×10^{-9} g dose remaining after 24.04 hours. [2]

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- (e) Outline an ethical implication of using nuclear treatments in medicine. [1]

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(Option D continues on the following page)

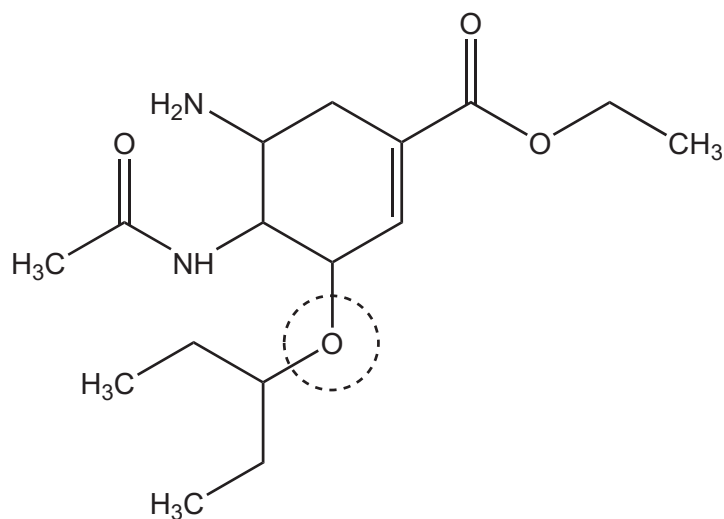


(Option D continued)

- 26.** In recent years several antiviral medications have been produced. One of these medications is oseltamivir (Tamiflu).

(a) Identify the functional group circled in the structure of oseltamivir.

[1]



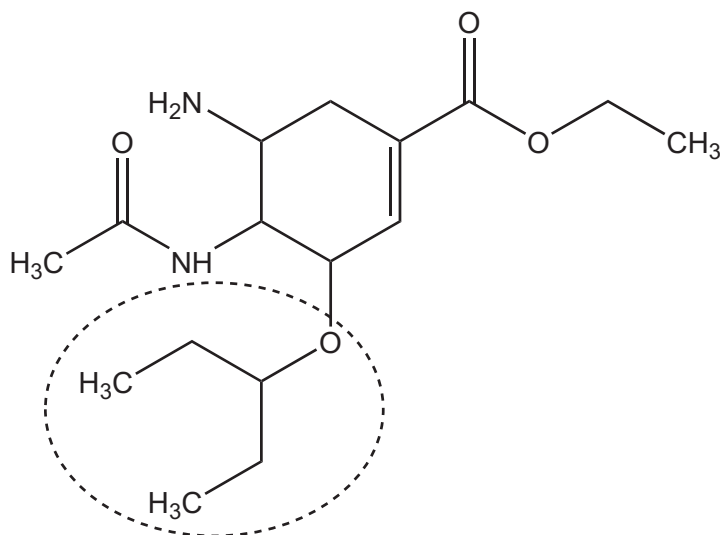
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(Option D continues on the following page)



(Option D, question 26 continued)

- (b) Predict the number of signals and relative integration you would expect to see in the nuclear magnetic resonance spectroscopy (^1H NMR) spectrum for the circled portion in the structure. [2]



Number of signals:

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Relative integration:

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- (c) Oseltamivir is a chiral compound.

- (i) Identify an apparatus that can be used to distinguish between its enantiomers. [1]

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(Option D continues on the following page)



(Option D, question 26 continued)

- (ii) Explain how the differentiation between the enantiomers is obtained using this apparatus.

[2]

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End of Option D



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40EP40